ICIP Institut canadien pour les innovations en photonique
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# Canadian Photonic Kit

## INDEX

# PHOTONICS: 50 YEARS OF LASERS!

*Photonics teaching kit intended for Secondary Education/high school students.*

## Tips for conducting the activity

Photonics is the science of generating, transmitting, treating (modulation, amplification) or converting light in other types of signals. The term photonics is relatively recent and is mostly reserved to technologies such as lasers, light-emitting diodes (LED) and optical fibres. Photonics is a modern addition to optics, a science that uses mirrors, lenses and prisms… One could compare the relationship between photonics and optics to the link between electronics and electricity.

We hope that this teaching kit helps stimulate an interest in photonics for secondary education level (Grade 9-12 in English Canada). It consists of seven easy experiments to be done with the students and we hope this will help them understand the particular aspects of light's behavior in today's modern technology. This teaching kit is intended for teachers, students and researchers who wish to act as activity leader. Our goal is to help you to catch the student's interest and to make science interesting for young people. It will be important that you use a vocabulary that can be understood by everyone, so remember to leave your technical jargon aside. This will help to raise interest for those who might have difficulty understanding a more technical approach. Naturally, this should not prevent you from using the correct terms so they understand; but please remember to always explain clearly what you are referring to. Some students will have no idea of what a photon or an atom is. Make sure to explain the concepts clearly. One thing to remember is to keep it simple, clear and precise. Take the time to interact with them so as to create an interest from the start. This will be a win/win situation; time spent with them will be very pleasant.

The procedure we propose is simple. Once in class, present yourself and say a few words on the world of photonics. Then, separate the students in **six** groups while giving out the material they will be using for the experiments. The complete material needed for each experiment is the bags. The bags are numbered to indicate the order for each experiment. The first experiment is first done since knowledge acquired by it will be needed to do experiment number 2, and so on. The material also contains an instruction sheet for students, so remember, your role as leader at this moment is to advise them. Circulate and let the students do the experiment themselves. You may give advice when needed as well as lend a hand when necessary.

After 10-15 minutes ask the teams of students to come one team at a time and repeat their experiment in front of the class. Let the students express themselves on what scientific phenomenon they have witnessed. Question them and direct the discussion. **Reminder: The order of the presentation is important; comprehension of one experiment will help to understand the next one.**

The following paragraphs will give you the information needed to popularize the field of photonics for students. Each experiment is explained in detail and comes with information with the objective of triggering interest in science and understanding many concepts. We encourage you to provide additional comments to the students after they have presented their experiment to the rest of the group and have tried to explain the phenomenon by themselves. Your group animation would then be better and the presentation more interesting!

At the start of your presentation about the field of photonics, use the comic strip to explain the functionality of a laser. The fun comic strip will surely help you break the ice.

Note: There is only one safe class 2 laser in the kit. To facilitate the workshop, we recommend that you borrow other class 2 lasers from your department, school or organization since a laser is needed for experiments 4, 5 and 6.

## Summary of the experiments

* This section presents the information provided in each bag. It is followed by a list of equipment and a section presenting more information and details on each experiment.

### Experiment 1 - Light = Energy (STUDENT GROUP 1)

**CAUTION:** The radiometer and the polarizers are fragile. Handle with care!

1. Take the radiometer out of its box.

2. Bring the radiometer near various sources of light in the classroom (light bulb, neon, natural light, etc.) and observe what happens. Try with the flashlight!

3. Vary the distance between the radiometer and the light source as well as the angle between the radiometer and the light.

4. Count how many rotations the lozenges of the radiometer make in a ten second span in order to determine which light sources are the most intense.

**CHALLENGE: Build a polariscope**

1. Take the polarizers (two plastic squares) out of the "Magic Stripes" bag.

2. With one hand, hold a polarizer and the fork or the small plastic box in front of that polarizer.

3. With your other hand, hold the second polarizer and align it with the first one at about a 5 cm distance.

4. Turn the second polarizer clockwise and observe what happens.

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### Experiment 2 - Invisible Light (STUDENT GROUP 2)

**Step 1**

a. Connect the piezoelectric emitter (the black buzzer) to the photovoltaic cell (the small solar panel) using the alligator clip wires. Connect the black wire to the negative post ( - ) and the red wire to the positive post ( + ).

b. The emitter will make a continuous sound. Cover the panel with a book to stop the sound.

c. Turn on the white LED light (the one **without** the red ribbon). Your eyes will be able to see the light.

d. Slightly raise the book while keeping the battery covered and bring the LED light close to the photovoltaic cell. What happens?

e. Turn on the LED infrared light (the one **with** the red ribbon). Your eyes will not be able to see the light.

f. Bring the LED infrared light close to the photovoltaic cell. What happens?

g. Then, take the remote control and point it towards the photovoltaic cell. Press any key on the remote control. What happens?

The infrared rays are invisible to the naked eye, but if you use a digital camera that captures the light rays, you might be able to see them on the camera. Note: Some cameras have filters to block the infrared light and may not capture the infrared LED.

**Step 2**

a. Turn on the digital camera. Keep your finger on the button for at least 2 seconds to turn it on.

b. Point the LED infrared light towards the camera lens while keeping an eye on the camera screen.

c. Point the remote control towards the camera lens while keeping an eye on the screen. Press on any button.

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## Experiment 3 – Bright Sound! (STUDENT GROUP 3)

**CAUTION**: The light from the laser may be dangerous for your eyes; never point it towards someone or look into the laser beam.

* Go to a corner of the room to carry out this experiment. You will also need a MP3 player.

**Step 1**

a. Install the flat back speaker.

b. Stabilize the receiver and the laser transmitter firmly with the tripods. Careful! The tripods are delicate. Fix each black box to its tripod using the little screw on top of the tripod.

c. Stretch each foot of the tripods to an inch.

d. Turn on the black boxes by inserting the plug in the hole beneath each box. A red light indicates that the receiver is turned on, and the laser lights on from the laser transmitter. CAUTION! Point the laser transmitter towards a table or the ground when turning it on.

e. Connect the speaker to the receiver. Turn on the speaker by pressing the grey switch on the left side. A blue light indicates that the speaker is on.

f. Connect a MP3 player to the laser transmitter and turn it on.

g. Align the laser beam precisely towards the target on the receiver's window by stretching more or shrinking the transmitter's tripod until you hear some music.

h. Test this procedure at different distances!

**Step 2**

a. Install the first mirror in front of the laser transmitter in such a way that the ray is deflected. * Tip: Reflect the laser beam towards a wall (or by making a shield using a book); this will help you direct it more easily.

b. Identify the spot where the beam hits and install a second mirror so the beam will be deviated again.

c. Then find the spot where this beam hits and install the third mirror so that the beam is deflected towards the receiver.

d. Useful tip: You might have to raise some mirrors using books.

e. Align the laser beam with the target on the receiver until you hear music.

## Expérience 4 - Deep Reflections (STUDENT GROUP 4)

CAUTION: The light emitted from the laser is dangerous for your eyes; never point it towards someone or look into the laser beam.

**Step 1**

a. Find a room or a corner where it is dark. Face the wall.

b. Put the small LED lamp on one end of the acrylic band and turn it on by pressing on it.

c. Play with the angle of the lamp so as to see the light reflect inside the acrylic band and watch it emerge at the other end.

d. Repeat steps b and c using a laser provided by the workshop leader. CAUTION: Do not look directly at the tip of the acrylic band.

For better results, turn off the lights for the next steps.

**Step 2**

a. Use the tip of the wooden stick to measure the quantity of milk powder to pour in the water bottle.

b. Fill the water bottle up to 600 ml and dissolve milk powder.

c. Pour the water and milk solution in the tennis ball container. Use your finger to block the hole on the side of the container. To prevent spilling water, put the container in the plastic collecting basin.

d. Keep your finger on the hole! Light on the small LED lamp by pressing on it and install it on the side of the tennis ball container. Point the light towards the ceiling and through the container. Observe how the light propagates.

e. Turn off the light and repeat the experiment with the laser provided by the workshop leader. Observe.

**Step 3**

a. Place the tennis ball container in the collecting basin; make sure the hole faces the arrow traced on the bottom of the collecting basin. Don't take off your finger from the hole just yet!

b. Direct the LED lamp in the hole and take off your finger in order to let the water out.

c. Observe: where is the ray of light directed?

d. Refill the tennis ball container using the water of the collecting basin.

e. Repeat steps a, b, and c using the laser provided by the workshop leader.

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## Experiment 5 - Bundle of Light (STUDENT GROUP 5)

**CAUTION**: The light from the laser may be dangerous for your eyes; never point it towards someone or look into the laser beam.

1. Wind the fishing line approximately 10 times around the length of the stick.

2. Cut the line from the roll.

3. Cut the line at both ends of the stick.

4. Insert the strands of line in half a black straw.

5. At one end of the straw, make sure that all the strands are of equal length. On the other end, they should form a brush.

6. Take the LED light and turn it on by pressing it.

7. Light up the end of the straw where the strands are equal.

8. Observe the other end of the straw.

9. Repeat steps 8 and 9 using the laser provided by the workshop leader. CAUTION: Do not look directly at the laser beam coming out of the strands.

### CHALLENGE

1. Take one strand of fishing line.

2. Make a large knot in the middle.

3. Take a laser and light one end of the strand until you see the laser beam coming out at the other end (you may have to loosen up the knot a little).

4. Tight the knot gently, until you do not see the laser beam coming out at the other end of the strand.

5. Measure the knot diameter.

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**Expérience 6 - Unexpected Images (STUDENT GROUP 6)**

**CAUTION**: The light from the laser may be dangerous for your eyes; never point it towards someone or look into the laser beam.

1. Lay the plastic square flat on the table.

2. Place the frame with diffraction gratings about 20cm above the plastic square.

3. Point the flashlight on the small squares of the diffraction gratings.

4. Turn off the lamp and point the laser (provided by the workshop leader) on the squares.

5. Try on all the squares of the frame with diffraction gratings.

6. Move the diffraction gratings away from the white square. You will notice the forms become bigger at longer range.

**BONUS ACTIVITY**

1. Take the "Rainbow People" plastic bag.

2. Turn on the flashlight and look at the light through the cardboard circle. You can also look at various light sources, but not a laser, through that circle.

3. Now take the laser and point it through the cardboard circle towards the plastic square on the table.

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## Experiment 7 – Moving Images (STUDENT GROUP 6)

**CAUTION:** The lamp becomes very hot. Do not touch the bulb directly.

1. Carefully take the hologram (the rectangular black plastic) out of its pouch.

2. Put the hologram on the easel; white stickers indicate the top and back side of the hologram.

3. In a dark corner of the room, plug in the lamp and turn it on.

4. Place the lamp at about 1 meter in front of the hologram.

5. Lower the lamp so to find the ideal angle to see the images.

6. Continue to light the hologram while moving sideways to see the moving and changing images.

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## List of equipment included

| Main box |
|---|
| 2 booklets for the activity leader Fr/Eng |
| 3 printed comic strips |
| 1 poster - Electromagnetic Spectrum |
| 1 partners CD |
| 2 partners booklet, Fr/Eng |
| **Activity leader bag (Animateur)** |
| 1 small blue bag |
| 1 audio-video wire for the camera in kit #2 |
| 1 optical-fibre cable |
| 1 box of Spare batteries (2x2a, 2x3a, 1x9v) |
| 1 laser pointer (class 2) for activity #4, #5, #6 |
| **Experiment #1 - Light = Energy** |
| 1 large blue bag |
| 2 instruction cards Fr/Eng |
| 1 radiometer |
| 1 DEL flashlight |
| 1 OSA experiment "Magic Stripes" |
| **Experiment #2 - Invisible Light** |
| 1 small blue bag |
| 2 instruction cards Fr/Eng |
| 1 TV remote control |
| 1 digital camera |
| 1 buzzer and 2 alligator clamps |
| 1 PV (solar) cell |
| 2 light bugs - white and IR |
| **Experiment #3 - Bright Sound** |
| 1 large blue bag |
| 2 instruction cards Fr/Eng |
| 3 mirrors 5X15 cm with plastic stands |
| 1 flat speaker |
| 1 receiver on a tripod |
| 1 laser transmitter on a tripod |

| Experiment #4 - Deep Replections |
|---|
| 1 large blue bag |
| 2 instruction cards Fr/Eng |
| 1 x 90 ml pot of powder milk |
| 1 wooden stick |
| 1 light bug DEL |
| 1 bended acrylic flat bar |
| 1 tennis ball bucket |
| 1 square plastic bucket |
| 1 600ml plastic bottle |
| **Experiment #5 - Bundle of Light** |
| 1 small blue bag |
| 2 instruction cards Fr/Eng |
| 1 light bug DEL |
| 1 fishing yarn roll of 183 m (40 lbs) |
| 2 wooden pieces 2,5X16,5 cm |
| ± 50 plastic straws |
| 1 chisel |
| 1 OSA experiment "Rainbow Peephole" |
| **Experiment #6 - Unexpected Images** |
| 1 small blue bag |
| 2 instruction cards Fr/Eng |
| 1 light bug DEL |
| 1 diffraction network |
| 1 white plexiglass square 7 ½ X 7 ½ cm |
| **Experiment #7 - Moving Images** |
| 1 large blue bag |
| 2 instruction cards Fr/Eng |
| 1 wooden easel |
| 1 hologram |
| 1 projector |
| 1 light bulb 50W |

# Detailed presentation of each experiment and additional information

## EXPERIMENT 1 – Light = Energy!

Imagine a standard 100 watt incandescent light bulb. As your eyes will confirm, it emits light in all directions. And, as your skin will tell you, if you put your hand near the bulb, you will feel heat radiating in all directions.

Light and heat are two forms of energy. We refer to them as luminous energy and thermal energy. Is there a way that these forms of energy can be transformed into mechanical energy, i.e. movement? This is what Sir William Crookes, the English chemist and physicist, succeeded in doing in 1873 thanks to a fairly simple invention.

The **Crookes radiometer**, also known as the *light mill*, consists of an airtight glass globe, containing a partial vacuum leaving relatively few air molecules within. Inside are a set of four branches and at the end of each is a small lozenge that is black on one side and white on the other. The apparatus is balanced on a spindle that allows it to rotate freely with very little friction.

As its name suggests, the radiometer measures the intensity of the radiation that it detects. As light shines on the light mill, it begins to rotate; the speed of the rotation depends on the intensity of the light.

1. Take the radiometer out of its casing.

2. Bring the radiometer near various sources of light in the classroom and observe what happens. Bring the students to try with the LED light included in the experience bag!

3. Vary the distance between the radiometer and the light source as well as the incident angle of the light.

4. Try to count how many rotations the radiometer makes in a ten second span in order to determine which light sources are the most intense.

What occurs within the radiometer? Although its invention dates back to 1873, the device's true operation was only correctly explained in 1879. Its operation is essentially based on the different properties of the black and white surfaces. White reflects a great deal of light while black absorbs a great deal of light. The light causes the black surface to heat up more than the white surface. Inside the globe, the small amount of air near the black surfaces warms up.

Consequently, there is a slight temperature variation at the surface of the lozenges depending on whether they are black or white. On the warm side, the air is less dense than on the cool side. The air pressure is therefore slightly lower. At the edge of the lozenges, the cool air has a tendency to move toward the side where the pressure is lower in order to restore the balance. This weak displacement of air from the white side to the black side creates a slight push in the other direction, which is sufficient to induce rotation of the small device.

Allowing more air inside the Crookes radiometer would hinder its operation because of the resistance caused by the increased amount of air. It is interesting to note that if a total vacuum were created inside the globe, the lozenges would rotate in the other direction! This is because the photons (light particles) hitting the white sides would be reflected, which means that they would bounce off the surfaces. These tiny collisions would slightly push the lozenges and cause a rotation in the total absence of air.

Ultimately, this leads us to conclude that light can be converted into movement!

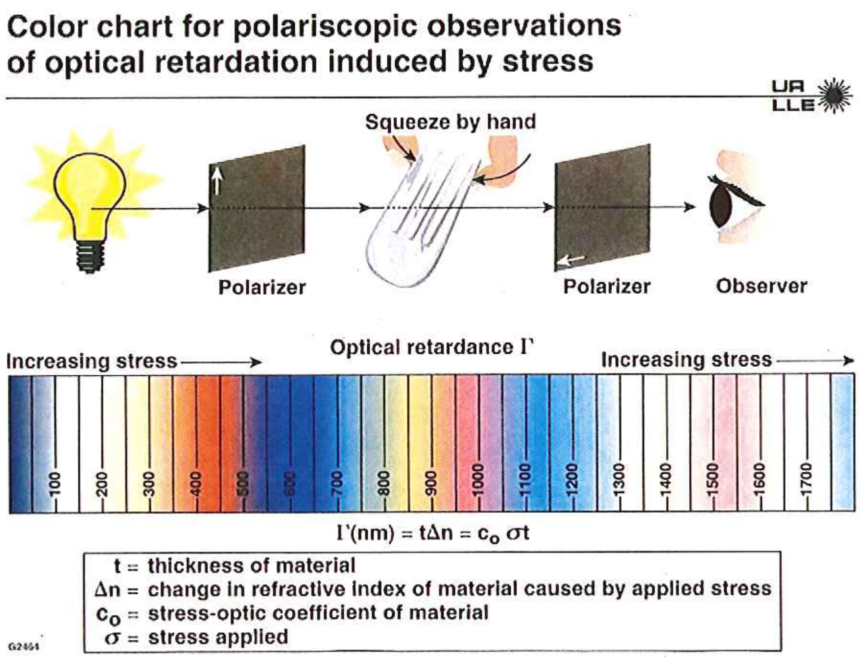
The principle of « light pressure » has inspired researchers who envision novel modes for space travel. In the vacuum of space, a ship equipped with a large reflecting sail facing away from the sun could be propelled at a great distance. And because of the continuous light flow pushing without stop, the ship could reach astonishing speeds! Light: a constant source of energy and totally free!

The Crookes radiometer also operates with non-visible radiation. Infrared radiation for example is very efficient in order to heat up the black surfaces of the light mill. If we were to bring our hands near the device, it would practically stop turning because the glass of the globe blocks (reflects) infrared light. However, if we were to place our hands directly on the globe that would heat the glass and infrared radiation would be emitted towards the interior, which would in turn cause the mill to rotate!

## Building a polariscope

Light is a wave oscillating in all direction perpendicular to its trajectory. However, we can limit the oscillation to one vertical or horizontal direction. When light is reflected on a surface, it becomes polarized in one direction. A polarizer is another way to limit the wave oscillating in a given direction blocking the waves oscillating in others. By using two polarizers, we can completely block the light by rotating one of the polarizer. Polarized sun glasses use that mechanism to stop light reflected by surfaces. Screens of cellular telephones and calculators also use polarization and therefore, it is possible to darken the screens with a polarizer.

A polariscope can be built by holding two polarizers back to back as shown in the drawing. Since making a piece of plastic generates internal stress and since such stress affects the polarization of light, putting the plastic fork between the polarizers generates color which depends on the level of stress at different parts of the fork.



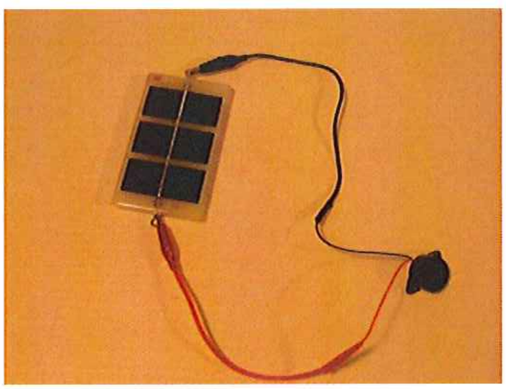
## EXPERIMENT #2 - Invisible Light

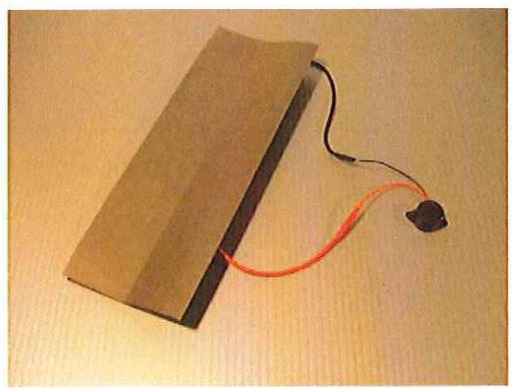
There is nothing unusual about turning on a television using a remote control device... But, did you know that your remote is in reality a small flashlight that blinks? In fact, the end of the remote control emits a "light" that reaches the TV's sensor. Why can't we see it? Because it is infrared light, a "color" our eyes can't detect. To better demonstrate that infrared is really a light, let's try the experiment below.

### Step 1

a. Plug the piezoelectric transmitter (the black buzzer) into the photovoltaic battery (the small solar panel) using the alligator clip wires. Connect the black wire to the negative post ( - ) and the red wire to the positive post ( + ).

b. If the ambient light is strong enough the transmitter will make a continuous sound. Cover the panel with a book to stop the sound.

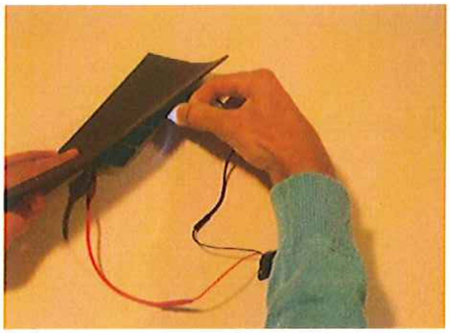


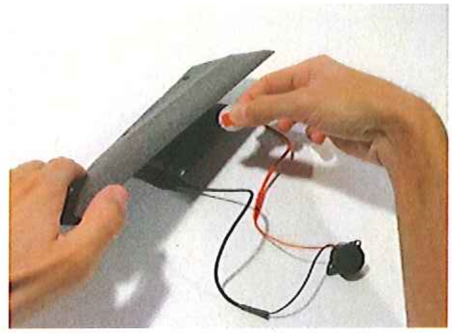


c. Turn on the white LED light (the one without the red ribbon). Your eyes will be able to detect the light.

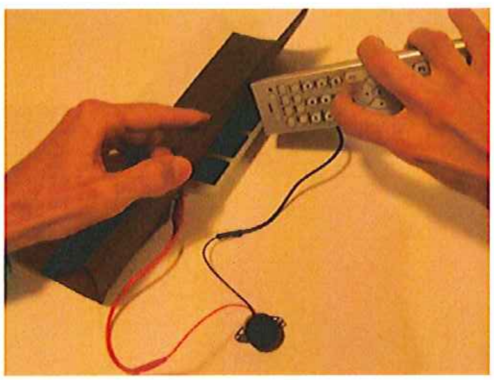
d. Slightly raise the book while keeping the battery covered and bring the LED light close to the photovoltaic battery. The transmitter will emit a continuous sound each time you approach the light.

e. Turn on the LED infrared light (the one with the red ribbon). Your eyes will not be able to see the light. And yet, if you approach the LED to the photovoltaic battery, the sound is still emitted. This demonstrates that the ray emitted is similar to light.





f. Now, take the remote control and point it towards the photovoltaic battery. Press any key on the remote control. The transmitter will make an uneven sound. What you are hearing is the coded signal that the remote sends to the TV: an infrared flashing light!



Can we see the infrared light? Not really, but if we use a screen to convert it into visible light, then we will be able to see it.

**Step 2**

a. Turn on the digital camera. Keep your finger on the button for at least 2 seconds.

b. Point the LED infrared light towards the camera lens while keeping an eye on the camera screen and even if your eyes can't see anything directly on the LED light.

c. Repeat the procedure using the remote control so you may "see" it blink.

Note: You can follow this visual element on a big screen. Simply plug the camera in the projector using the supplied cable.

Digital cameras are sensitive to infrared rays which have lower energy than red light. When they are captured they emit a blue-white light image on the screen.

Some low-cost night vision systems use this exact same infrared light procedure. In the dark, an infrared LED lights up objects invisible to the naked eye. A simple small digital camera sensitive to infrared light permits "to see" these objects in the dark.

**Hunting... with the help of infrared lights**

Some snakes such as rattlesnakes, pythons and boas detect infrared light emitted by hot blooded mammals for hunting. The rays are "seen" with their infrared receptors. These are located along their upper jaw. The receptors capture infrared rays, even low intensity ones, and the snake's brain decodes the signal in the same way a mammal would sense pain. The signal is analyzed by the snake's brain and then, it reconstructs a thermal image so that the snake can follow its prey. This is what makes this reptile such a great nocturnal hunter.

Anecdote: Snakes are not the only predator using these rays to their advantage. The ground squirrels from California use them as well to foil their predators. In order to protect their young from rattlesnakes, adult squirrels will turn up the heat in their tail. This tactic makes it seem as if there were abnormally big adult squirrels around. Thus, the snakes are discouraged from the hunt. An ingenious use of infrared radiation!

## Experiment #3 - Bright Sound!

Recently, different types of technologies have enabled us to send data without cables. Using radio waves we have today several means to send out information all around the world. The problem encountered by these technologies is that they all reach their limit at some point... For example, when the information reaches an obstacle it can become blurred and sometimes it doesn't get to its intended destination. For some time now, researchers have been working on means to transmit information very rapidly without losing bits and pieces here and there... by using...light!

Let us now take a look as to how to make information travel possible, be it a simple coded signal or something as complex as music...

**<u>CAUTION:</u>** The laser used in this experiment is one of class 2. The light is **<u>dangerous</u>** for your eyes; **<u>never</u>** remove the laser from the stand or point it towards someone's eyes.

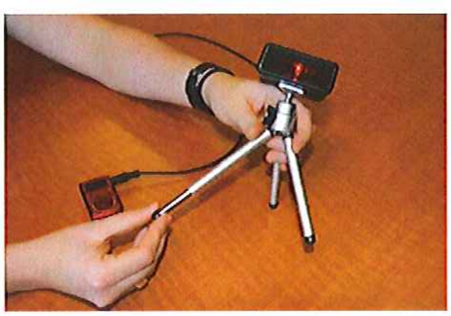
Find a location in a corner of the room to carry out this experiment. Students will also need an MP3 player. Either you think of bringing your own one or ask for a volunteer to have one for use in the classroom.

### Step 1

a. Install the flat back speaker.

b. Stabilize the receiver and the laser transmitter firmly with the tripods. Careful! The tripods are delicate. Fix each black box to its tripod using the little screw on top of the tripod.

c. Stretch each foot of the tripods to an inch.



d. Turn on the black boxes by inserting the plug in the hole beneath each box. A red light indicates that the receiver is turned on, and the laser lights on from the laser transmitter. CAUTION! Point the laser transmitter towards a table or the ground when turning it on.

e. Connect the speaker to the receiver. Turn on the speaker by pressing the grey switch on the left side. A blue light indicates that the speaker is on.

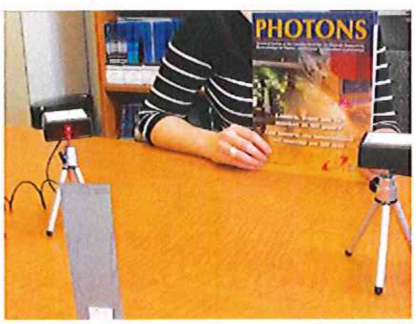
f. Connect a MP3 player to the laser transmitter and turn it on.
g. Align the laser beam precisely towards the target on the receiver's window by stretching more or shrinking the transmitter's tripod until you hear some music.

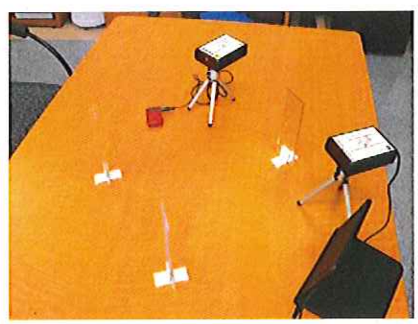
h. Test this procedure at different distances!

**Step 2**

**CAUTION:** **<u>Never</u>** place yourself so your eyes are directly in front of the laser transmitter to observe the laser ray. **<u>Never</u>** look at the laser ray directly in the mirror.

a. Install the first mirror in front of the laser transmitter in such a way that the ray is deflected. * Tip: Reflect the laser beam towards a wall (or by making a shield using a book); this will help you direct it more easily.



b. Identify the spot where the beam hits and install a second mirror so the beam will be deviated again.

c. Then find the spot where this beam hits and install the third mirror so that the beam is deflected towards the receiver.

d. Useful tip: You might have to raise some mirrors using books.

e. Align the laser beam with the target on the receiver until you hear music

What a revolution! Using rays of light to make information travel! Have you noticed that the music you listen to is crystal clear? There is no interference or distortion. We can even give light another trajectory thanks to mirrors. The only condition for it to work: no obstacles...

How does music travel through laser rays?

Let's start by discovering the purpose of the small black boxes. The first box, the one called "laser transmitter" emits luminous signals. We connect an MP3 player to this box and music, which is in fact a series of small variations in an electrical signal, is converted in a series of variations inside a luminous signal. However, these variations are too small and too quick to be seen by the naked eye.

The other box, the one called "receiver", receives luminous signals. Its electronic components allow the conversion of the luminous signal into an electric signal. This signal then makes the speaker vibrate and much to our pleasure enables us to hear music!

**The route from photo phones to telephones**

Did you know that the first sound transmissions were made using light? The photo phone was the first voice transmitting device invented in 1880 by Alexander Graham Bell, the inventor of the classic telephone. The photo phone worked by using the light from the sun and a setup of mirrors. The operation was the same as in the experiment that you have just done.

Let us explain how a photo phone works: the voice, amplified by a microphone, creates vibrations in a mirror which reflects sunlight. At a distance of up to 200 meters, another mirror captures the reflected light from the first mirror and creates vibrations in a device that reproduces the sound. This receiver is almost identical to the telephone invented a few years before.

Graham Bell considered the photo phone invention as his most important technological progress, mainly because we could communicate without wires.

The big drawback of the invention was that as soon as a cloud covered the sun, communications were interrupted... one could easily see that wire communications were more practical. This was true until the day that wireless communications were again brought in the limelight...

## Experiment #4 - Deep Reflections

Have you ever stopped to look at your feet in a swimming pool? Have you ever had the chance to observe a mirage in the summer? Light, which usually travels in a straight line, can take different directions depending to the matter is passes through. It can even be trapped...

**CAUTION:** light emitted from laser is **dangerous** for your eyes; **never** point it towards someone.

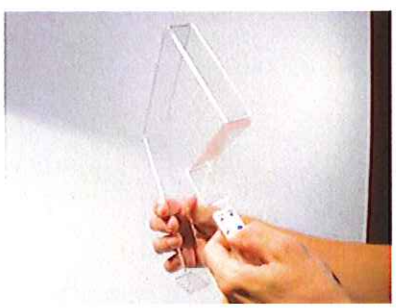
In this experiment it is recommended to find a dark room or a dark corner so you can better observe.

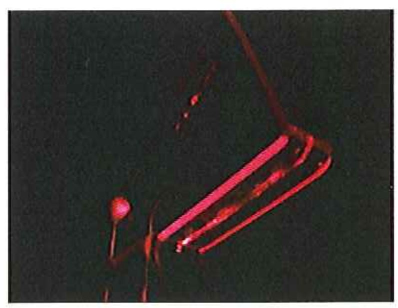
### Step 1

a. Use the folded acrylic band, the LED lamp and the laser from the leader's bag.

b. Put the small LED lamp on one end of the acrylic band and turn it on by pressing on it.

c. Play with the angle of the lamp so as to see the light reflect inside the acrylic band and watch it emerge at the other end.





d. Repeat steps b and c using the laser provided in the leader's bag. CAUTION: Remind students not to look directly at the tip of the acrylic band.

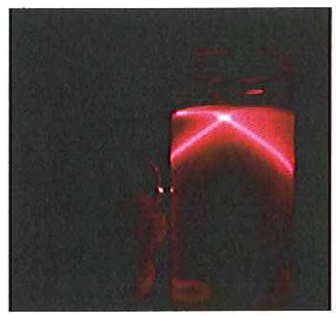
*For better results, turn off the lights for the steps 2 and 3.*

**Step 2**

a. Use the tip of the wooden stick to measure the quantity of milk powder to pour in the water bottle.

b. Fill the water bottle up to 600 ml and dissolve milk powder.

c. Pour the water and milk solution in the tennis ball container. Use your finger to block the hole on the side of the container. To prevent spilling water, put the container in the plastic collecting basin.



d. Keep your finger on the hole! Light on the small LED lamp by pressing on it and install it on the side of the tennis ball container. Point the light towards the ceiling and through the container. Observe how the light propagates.

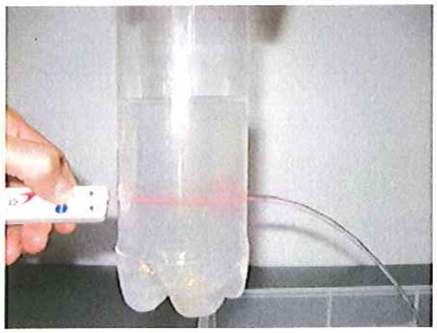
e. Turn off the light and repeat the experiment with the laser provided in the workshop leader's bag. Observe.

**Step 3**

a. Place the tennis ball container in the collecting basin; make sure the hole faces the arrow traced on the bottom of the collecting basin. Don't take off your finger from the hole just yet!

b. Direct the LED lamp in the hole and take off your finger in order to let the water out.

c. Observe: where is the ray of light directed?




d. Refill the tennis ball container using the water of the collecting basin.

e. Repeat steps a, b, and c using the laser provided in the workshop leader's bag.

**If the laser ray does is not seen in the jet of water, ask the students to direct the laser ray towards the jet.

Even without using a mirror, light can be reflected and remain captive in the center of certain substances. It is merely a question of refractive index and angle.

The light that passes from one medium to another is refracted. An example of this is when we put a pencil halfway in the water. We are under the impression that it is "broken" but this is only an illusion. The reality is that the rays of light that our eyes see are coming from different angles.

By passing from the water to the air the air, and vice-versa, the light rays are deviated. We are then under the impression that the object is broken because the rays of light which permit us to see through water is not at the same angle as the rays that show us the tip of the object outside the water.

When the rays pass from one material to another, a portion of the light is refracted and another part is reflected. In certain circumstances when the angle is small enough, light is entirely reflected. This is what we call total internal reflection. Light will "ricochet" on the walls and will propagate in the center where it is trapped.

In the experiment you have just done the internal surface of the water and acrylic band acted as internal mirrors.

All the luminous rays are imprisoned inside the "tube of water" and this gives us the impression that it "flows".

**Ingenious use of the total internal reflection phenomenon**

**A prospectors dream**

As you know, the luster of a diamond is due to the composition of the stone (pure carbon and sometimes inclusions) and many jewelers use the total internal reflection phenomenon to make the stone sparkle. The transparency of the diamond permits an easy entry and exit for light. However, it is possible to cut a flat surface in a precise angle so that the light is reflected on the sides of the stone and can only exit at the top. This is the reason why a diamond dazzles when you look down at it!

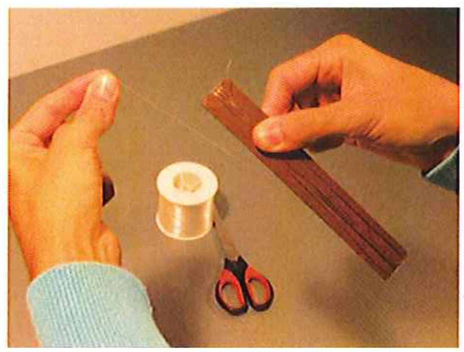
**Mysterious mirages**

A mirage is formed when the ground is heated by the sun. Heated air close to the ground becomes less dense. The refractive index of the warm air is smaller. The light from objects around (trees, mountains) which is directed to the ground passes from a refractive environment to a less refractive one. This light is deviated until it is subjected to a total internal reflection. This is mainly because its refractive index is greater for cold air than that of hot air. The rays of light are therefore deviated towards the sky... this is when we get the impression that the image seen comes from the ground! That's why many desert nomads that went lost claimed to have seen oasis...

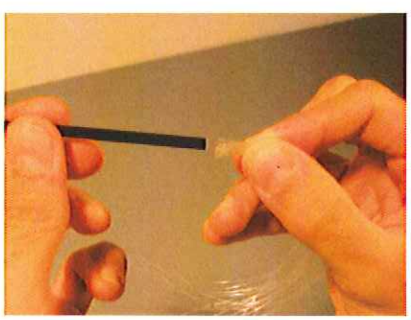
## Experiment #5 - Bundle of Light

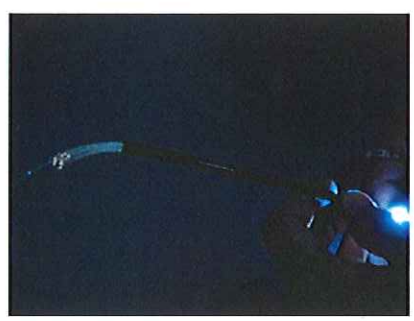
In today's age of computers, using light to send information is more wildly used. It's a method that's simple, extremely rapid and effective, and it won't break down because of the weather. But how do we send light to a precise location if the luminous wavelengths travel only in straight lines? The best way is to maintain the light in a material that makes it possible for it to travel by using total internal reflection. This material already exists: it's called optical fibres! An optical fibre is a long transparent tube made of glass or plastic covered by rubber sheathing. And guess what, you can make your own optical fibre!

1. You will be using a wooden stick and the roll of fishing line.
2. Wind the line (approximately 10 times) around the length of the stick.
3. Cut the line from the roll.



4. Cut the strands of the fish line at both ends of the stick. There will be roughly twenty stands of the same length.
5. Insert the strands in half a black straw.





6. At one extremity, make sure that all the strands are even. On the other end, cut them so they form a brush.
7. Take a LED light and light up the end of the straw where the strands are even.
8. Observe the other end of the straw. The light will emerge at the end of each strand.
9. Repeat steps 8 and 9 using the laser provided in the leader's bag. CAUTION: Remind students not to look directly at the laser beam coming out of the strands.

**CHALLENGE**

1. Take one strand of fishing line.
2. Make a large knot in the middle.
3. Take a laser and light one end of the strand until you see the laser beam coming out at the other end (you may have to loosen up the knot a little).
4. Tight the knot gently, until you do not see the laser beam coming out at the other end of the strand.
5. Measure the knot diameter.

**Supplemental experiment to be performed by the teacher**

Once the students have executed the experiments in front of the group, take out the material needed for experiment #3 ("A Luminous Sound!") and re-do the experiment using the optical fibre cable this time. Mention that while it may have been difficult directing the laser ray so that it went to the right place using the mirrors, there now is a cable designed to direct light and it is called: optical fibres!

1. Install the material from experiment #3 and turn on the MP3 player used at the time. Take the optical fibre cable and hold one extremity in the hole of the transmitter, then, take the other end and hold it in the receiver.
2. Ask someone to stretch the cable by moving the transmitter from the receiver while holding the fibres tips in the laser transmitter and the receiver.
3. Wind the cable and move it around.

Voilà! It is possible to make information travel by using light while directing its path using a light pipe!

Light travels through optical fibre thanks to a series of internal reflections. Light ricochets on the inner surface through the length of the fibre. This is called total internal reflection phenomenon (which we have discovered in the last experiment). Thanks to this principle, you can make light take the trajectory you want and especially, you can send information to many different locations at the same time! The light that is sent from the end of the optical fiber cable is directed along the tube and only comes out at the other end of the fibre.

The use of optical fibres has considerably enhanced communications between computers. Rather than using electric signals it is now possible to send luminous impulsions through fibres. These luminous impulsions are said to be "pure", meaning that they don't create interference. The light refracted in the fibre will be similar when it comes out of the wire to when it went in, it will have the same speed and the same information content. Furthermore, we are able to send much more information per second by using optical fibres than by using electrical wires!

**Optical fibres save lives!**

Medicine was the first field in which optical fibre was used. Nowadays, optical fibre is wildly used and helps improve diagnostics.

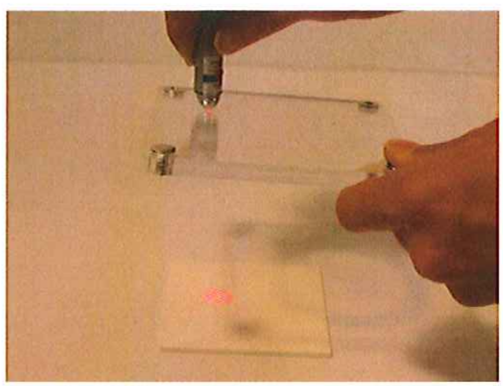
Notably, bundles of optical fibres are used in endoscopes to help in medical examinations inside the body. The equipment we have recourse to is called a Fibroscope. This is in fact a miniscule camera inserted in the human body so specialists can explore internal organs without surgery. Fibroscopes are used in biopsies, to explore the throat, the bronchial tubes, the colon and the stomach. This device lights up and transmits an image directly to the doctor, who can then make a reliable diagnosis and save lives.

## Experiment #6 - Unexpected Images!

The transparency of an environment can tell us astonishing things. Even if the environment seems transparent, is it really...?

**CAUTION:** This light is **dangerous** for your eyes; **never** point towards someone.

1. Lay the plastic square flat on the table.
2. Place the frame with diffraction gratings about 20 cm above the plastic square.
3. Point the flashlight on the small squares of the diffraction gratings.
4. Turn off the lamp and point the laser (provided in the workshop leader's bag) on the squares.
5. Try on all the squares of the frame with diffraction gratings.
6. Move the diffraction gratings away from the white square. You will notice the forms become bigger at longer range.



**BONUS ACTIVITY**

1. Take the "Rainbow People" plastic bag.
2. Turn on the flashlight and look at the light through the cardboard circle. You can also look at various light sources, but not a laser, through that circle.
4. Now take the laser and point it through the cardboard circle towards the plastic square on the table.

Each lid and each small square is a diffraction grating. Even if you can't see the phenomenon with your eyes, a series of lines and dots are engraved in the plastic. This etching is more opaque and does not let light pass through. When you direct the light from the laser onto the diffraction grating, light waves interfere in the process and this interference permits some of the zones to act as a new luminous source. The luminous sources emit in the same direction and as we have already seen the wavelengths emitted by a laser are straight, so it will emit in a straight line. This is how we are able to see the shapes!

This phenomenon is only possible when you use a laser light source; as we've seen in our experiment. Why is this? The reason for this is that the laser ray is in fact composed of several luminous rays that have a unique wavelength and that they all travel at the same time. This light is said to be coherent, because photons in the composition of the radiation are all in the same state, in the same direction, with the same frequency, the same polarization and have an identical phase. Light emitted in any other manner does not have the same property of luminous coherence. As rays are diffused in all directions they cannot respond in the same way.

A diffraction grating can make different forms appear but it can also permit the separation of the different wavelengths in white light, thus separate colors.

**Is a Compact Disc a diffraction network?**

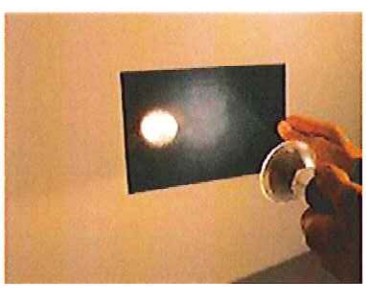
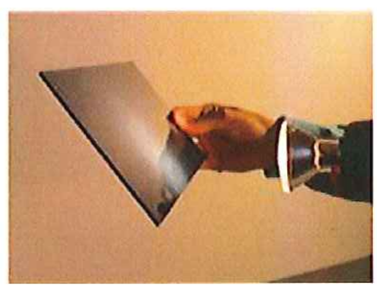
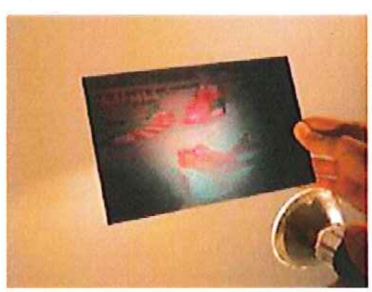
Yes, the Compact Disc does effectively act as a diffraction network! The disc is engraved with a series of very tiny, very close, parallel grooves. When they reach the surface of the Disc the waves that compose the white light are dispersed and reflected at different places depending on their color. Blue waves are reflected at a different angle then those of red or green color. This is the reason why we see all the colors of the spectrum when you look at a CD.

## Experiment #7 – Moving Images

A hologram is a photograph created by a special procedure when harnessing light. The photograph permits us to preserve the object's dimensions. Contrary to a classic photograph that only captures the intensity of the light, holography (the procedure which makes holograms possible) uses the principle of interference of the light waves to immortalize objects... Simple isn't it? The concept of exploiting light in this manner just required some thinking...

**CAUTION:** The lamp will burn. Do not touch the light bulb.

1. Take the hologram (the rectangular black plastic) out of its pouch and place it on the easel, the white sticker facing the back.
2. In a dark corner of the room, plug in the lamp and turn it on.
3. Place the lamp at about 1 meter in front of the hologram.
4. Lower the lamp so to find the ideal angle to see the images.
5. Continue to light the hologram while moving sideways to see the moving and changing images.

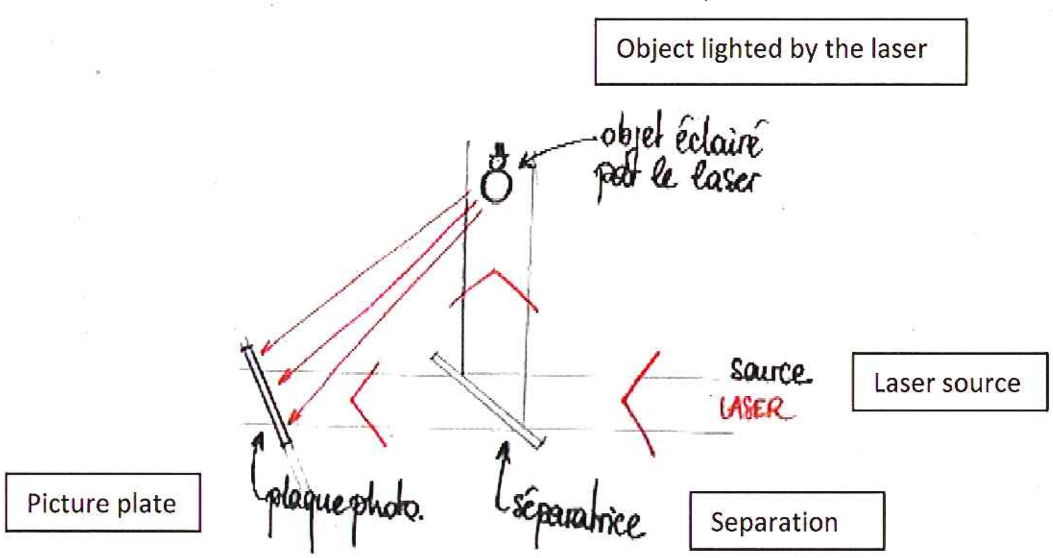
A hologram is a three dimensional image that appears to be suspended in the air. Indeed, by pivoting the image and looking at it from all sides, we witness three-dimensional depth perception. How is this possible?

To better understand how this works, first of all we must understand how holograms are made. To record a hologram we will need the following items:

- a holographic film (a plastic film called photopolymer);
- an object to holograph (and not to photograph);
- a semi-reflective mirror;
- a laser with a large beam.

We need a laser because we need a monochromatic coherent light in order to record a hologram. This means a light that has only one wavelength and one phase. It is precisely because of this reason that holograms are often in one color: a monochromatic light (one wavelength = one color) is used to record.

To record a hologram, you need to light up an object by reflecting the light from the laser towards the semi-transparent mirror. Some of these rays are reflected on the object, which then reflects the rays towards a photographic plate. The other rays pass though the semi-transparent mirror and light up the plate. We call this diffraction. Consequently, when the two separate laser rays meet on the recorded plate we witness interference. In some instances, the rays cancelled themselves and in others, they are amplified. Some zones then become darker (the image background corresponding to the object background) and other zones light up (the front of the image corresponding to the front of the object) and this creates the third dimension we see.



Here is an example of how holograms are formed: if you throw a pebble in the water, it creates small ripples. These will reach the shore without any difficulty. However, if you throw two pebbles instead of one, ripples will come from two different locations. These waves will reach the shore while colliding together. Thus, certain ripples will merge and grow bigger while others will be eliminated.

Holograms are images with astonishing properties. First off, the light reflected by the hologram on the object is exactly the same light as the object recorded when illuminated. You might compare a hologram to a window on an object. The image you perceive on the picture plate will depend on the angle in which you look at the holograph. This is the reason why we are under the impression that we see the object with "depth". Both of our eyes perceive the light coming from a different direction, so each one perceives a different image. The effect of depth is then reconstructed by our brain and we are under the impression that we are seeing the object in the same way it was "holographed". We can even notice different details depending on the angle in which we observe the hologram, certain details are hidden on the sides.

Impressive holograms have been created, some where you can even look into a microscope that has been registered as a hologram. And it works!

Now, imagine cutting a hologram into tiny pieces. Do you think you would obtain pieces of the holographic image, like you would in a puzzle? Well, think again. On every small piece you would see the entire image! Another example of this, image looking through a window; you will see the entire landscape, won't you? Let's go further. If you break the window and look through one piece of glass, would you see only a piece of the landscape? Or all of it? Holograms work in the same way! The only condition is to look at the image in the right angle. Fascinating, isn't it?

**Holographic movies?**

Thanks to re-inscribable holographs, we will soon be witness to a new type of 3D cinematographic image. The recording procedure is the same as in the classic holograph. The materials needed are a laser and a photopolymer plate which records the image.

The difference with this procedure is that the recording plate is composed of a new type of photo reactive polymer. The image is no longer definitely inscribed because the new plate will have a "rechargeable " memory. Instead of modifying the particles chemically using light or a regular plate, the charge will be modified in the plate itself. These charges can then be spread evenly by a sustained lighting. This way another image can then be recorded.